# Meridional heat transports in the ocean from an ECCO2 data synthesis

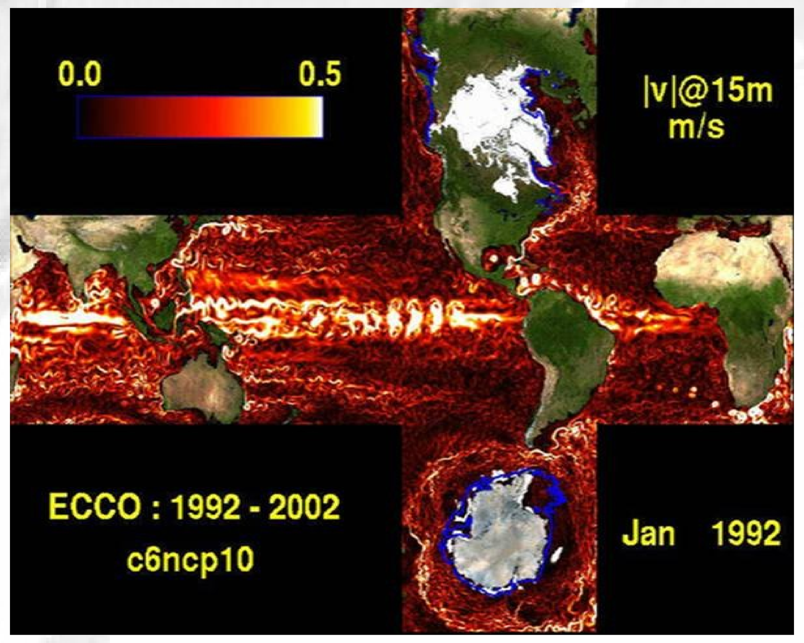
**Denis L. Volkov, Lee–Lueng Fu, and Tong Lee**

*Jet Propulsion Laboratory/California Institute of Technology*

*Contact: dvolkov@caltech.edu*

Jet Propulsion Laboratory
California Institute of Technology

## 1. ECCO2 Data Synthesis

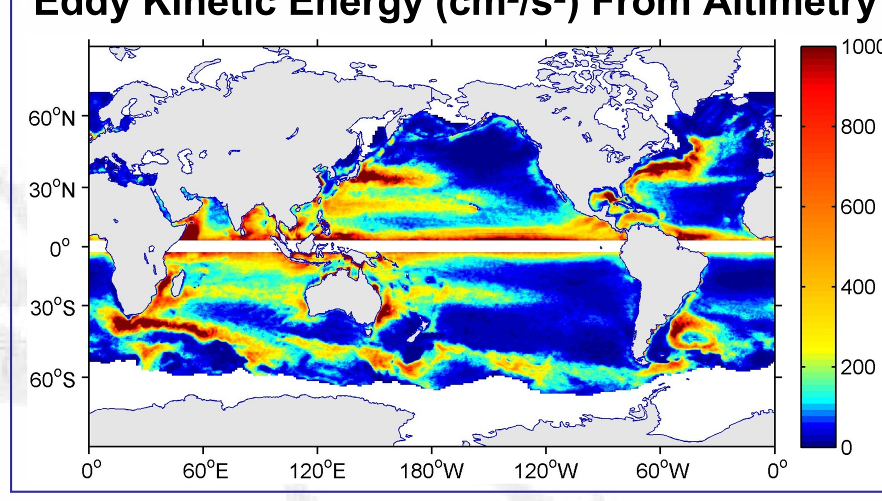



The Estimating Circulation and Climate of the Ocean, Phase 2 (ECCO2) project aims to synthesize available global-ocean and sea-ice data with a state-of-the-art ocean general circulation model at eddy-permitting resolution. An ECCO2 data synthesis is obtained by least-squares fit of a global full-depth ocean and sea-ice configuration of the Massachusetts Institute of Technology general circulation model to the available satellite and in-situ data using the Green's functions method.

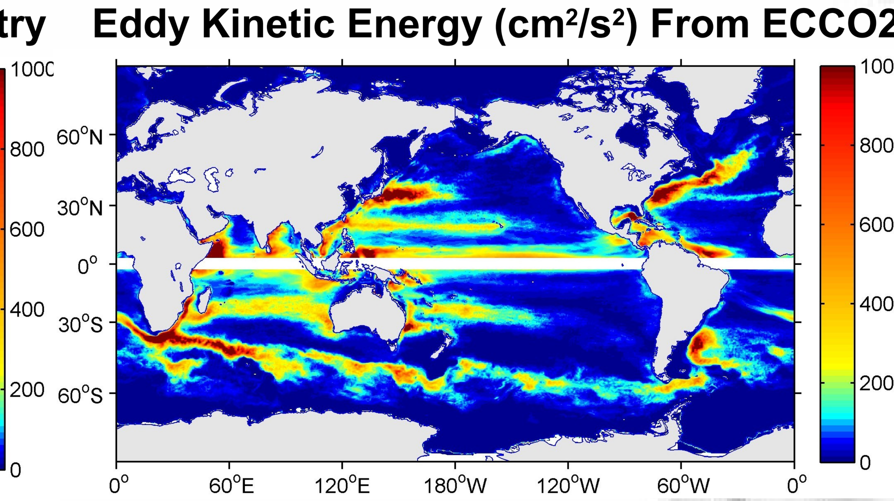
### ECCO2 Model Configuration:

- Cube sphere projection: 6 faces x 510 x 510 grid cells
- Mean horizontal resolution ~ 18 km
- 50 vertical levels with thicknesses from 10 m to 456 m
- Volume-conserving
- Bathymetry: General Bathymetric Chart of the Oceans
- Forcing: blend of NCEP/ECMWF/ERA40/CORE/ECCO-GODAE winds
- Initial conditions: WOA05
- Period of model run used: Jan 1992 – Dec 2001

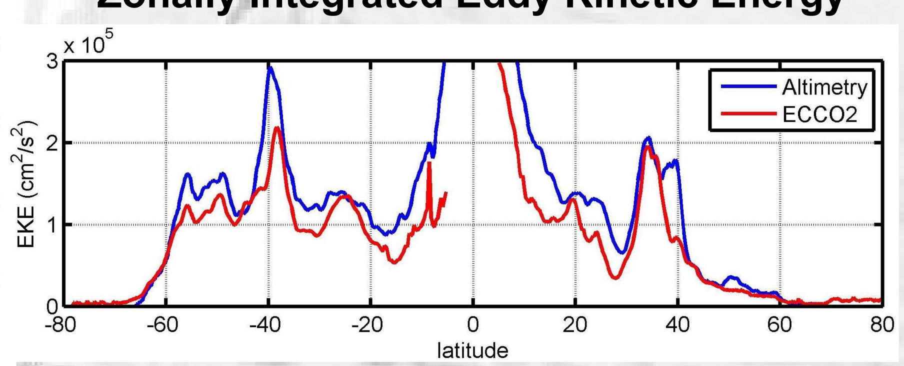
**Eddy Kinetic Energy ($cm^2/s^2$) From Altimetry**



**Eddy Kinetic Energy ($cm^2/s^2$) From ECCO2**



**Zonally Integrated Eddy Kinetic Energy**

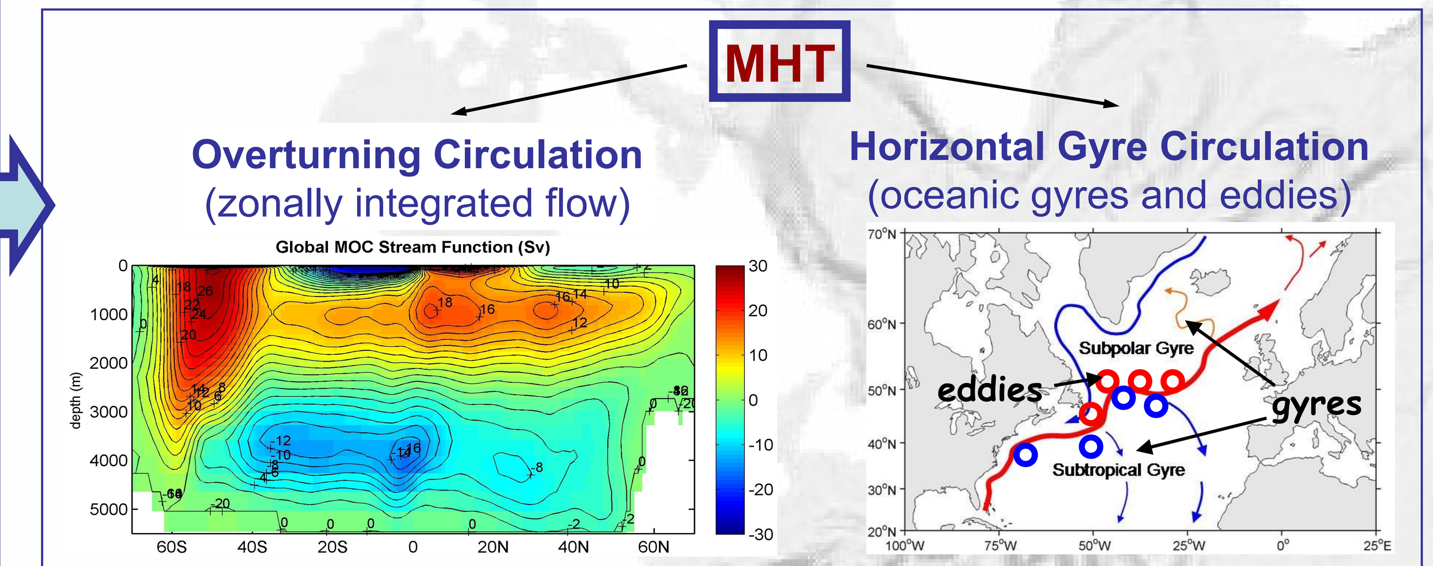



**Advantage of ECCO2 estimates:**

more realistic eddy field (model eddy kinetic energy (EKE) is comparable to altimetry EKE; differs from it by factor ~1.5)

## 2. Mechanisms of the Meridional Heat Transport

The oceanic meridional heat transport (MHT) can be decomposed into the heat carried by the *overturning circulation* (zonally integrated flow) and the *horizontal gyre circulation* (deviations from the zonally integrated flow), and into the heat transport due to the time-mean fields of the meridional velocity $V$ and temperature $\theta$ and due to the correlation between the time-varying fields of $V$ and $\theta$.




$$\bar{Q}(y,t) = \iint \rho C_p \begin{pmatrix} [\bar{V}][\bar{\theta}] \\ +[V'][\theta'] \\ +(\bar{V})^*(\bar{\theta})^* \\ +(V')^*(\theta')^* \end{pmatrix} dxdz$$

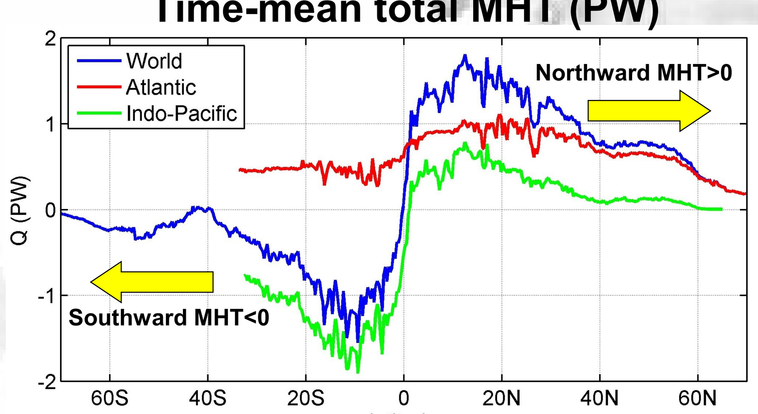
- $[\bar{V}][\bar{\theta}]$ – Time-mean overturning
- $[V'][\theta']$ – Time-dependent overturning
- $(\bar{V})^*(\bar{\theta})^*$ – Time-mean gyre transport
- $(V')^*(\theta')^*$ – Time-dependent gyre transport

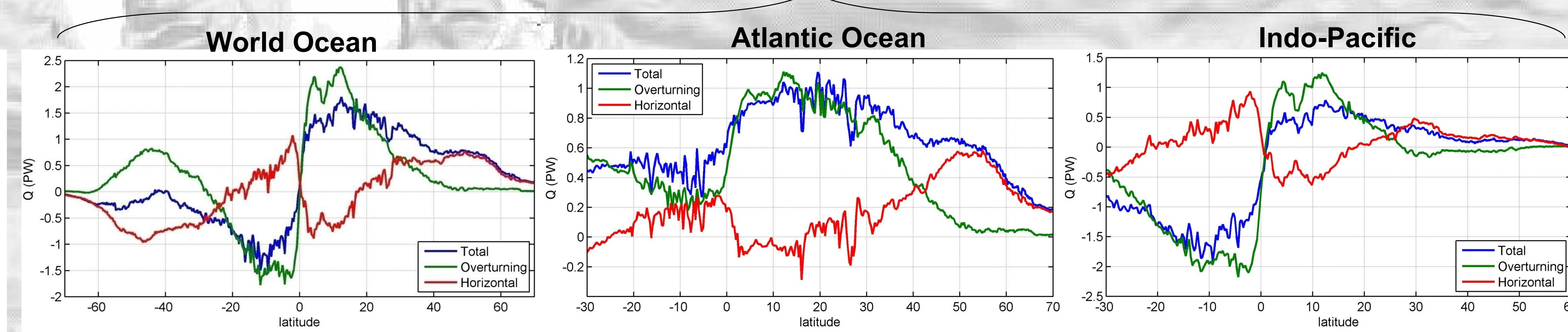
$\bar{V}, \bar{\theta}$ – time mean meridional velocity and temperature,
$V', \theta'$ – deviations from the time mean,
[ · ] – zonal average, ( · )* - deviation from the zonal average,
$\rho$ – density of seawater, $C_p$ – specific heat capacity of seawater.

## 3. Estimates of the MHT

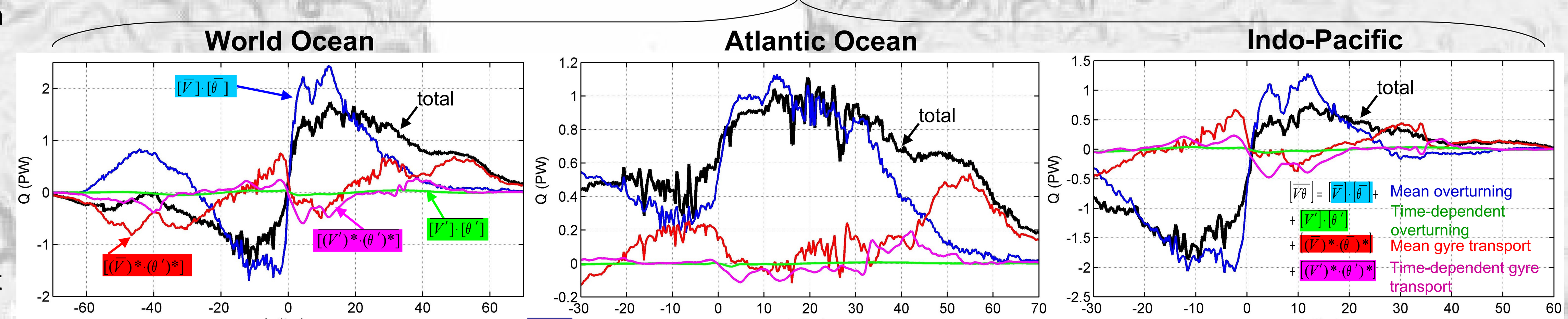
Components of MHT: $\overline{[V\theta]} = [\bar{V}][\bar{\theta}] + (\bar{V})^*(\bar{\theta})^*$

**Time-mean total MHT (PW)**




Components of MHT: $\overline{[V\theta]} = [\bar{V}][\bar{\theta}] + [V'][\theta'] + (\bar{V})^*(\bar{\theta})^* + (V')^*(\theta')^*$




- The time-mean of the total MHT is comparable to earlier studies based on coarser resolution models
- The MHT is mainly due to the horizontal gyre transport in the subpolar gyres, while the overturning dominates in the subtropical gyres
- The MHT is mainly due to the time-mean fields of V and θ
- The contribution of the time-dependent overturning is negligible

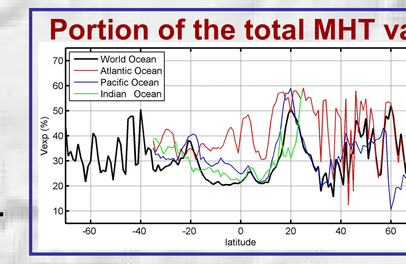
## 4. Eddy Heat Transport

$$Q(y,t) = \iint \rho C_p (\overline{\theta \cdot V} - \bar{\theta} \cdot \bar{V}) dxdz$$

The overbar indicates averaging over 3-month intervals (this work) or over all available data (earlier studies)

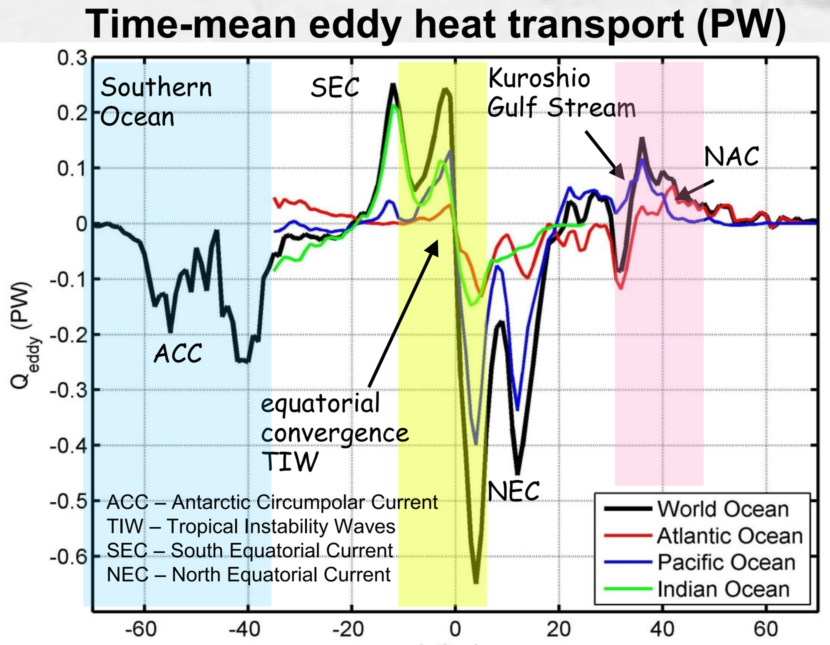
The estimated eddy heat transport (EHT) contains only signals with periods less than 3 months, which are mainly associated with the eddy variability. Our results show that the eddy heat transport has a significant contribution to the time-mean heat transport in the tropics, in the Southern Ocean, and in the Kuroshio Current.

**Portion of the total MHT variance explained by EHT**



- Globally EHT explains ~ 1/3 of the MHT variance

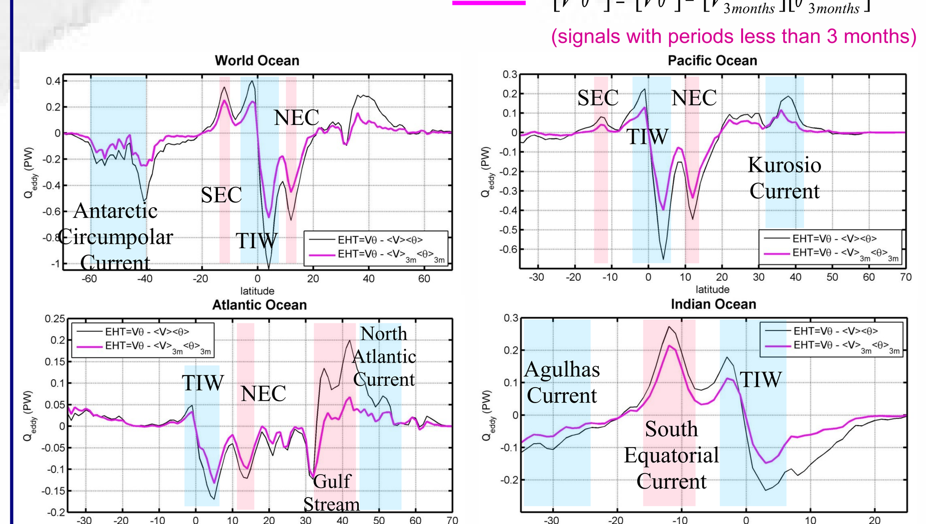
**Time-mean eddy heat transport (PW)**



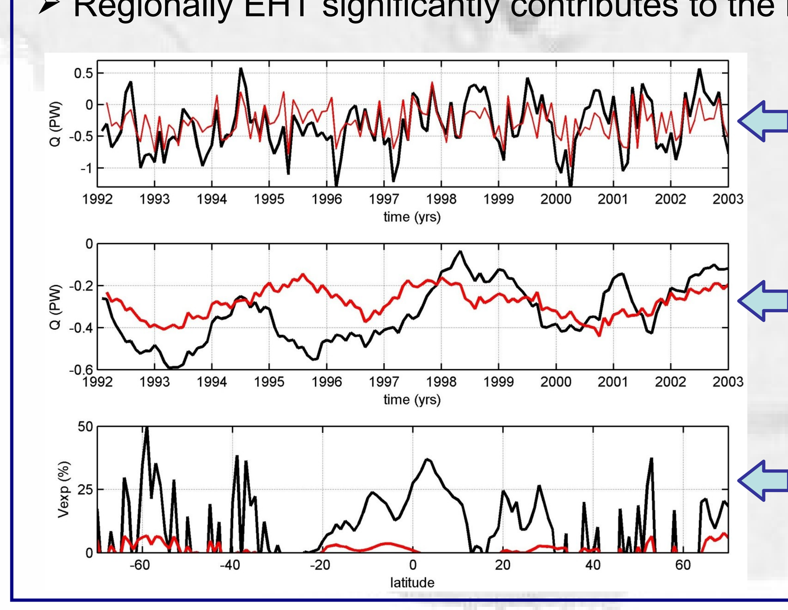

**Impact of the EHT definition:**

$\overline{[V'\theta']} = \overline{[V\theta]} - [\bar{V}][\bar{\theta}]$ (all variability)

$\overline{[V'\theta']} = \overline{[V\theta]} - [\bar{V}_{3month}][\bar{\theta}_{3month}]$ (signals with periods less than 3 months)




- Regionally EHT significantly contributes to the interannual variability of MHT



**MHT and EHT at 40°S**

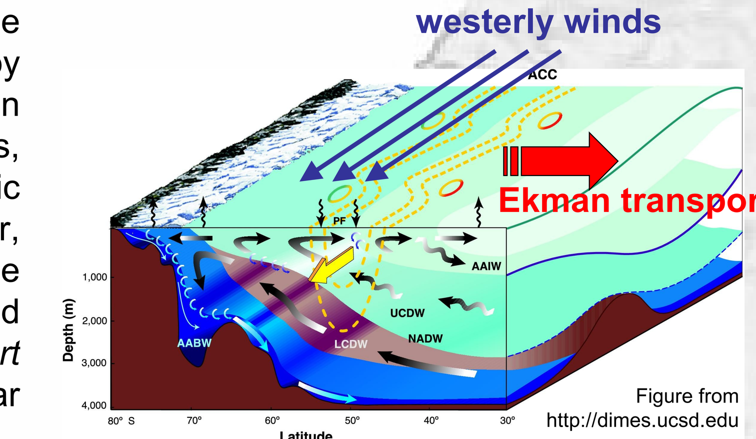
MHT
EHT

low-pass filtered with a 13-month running mean

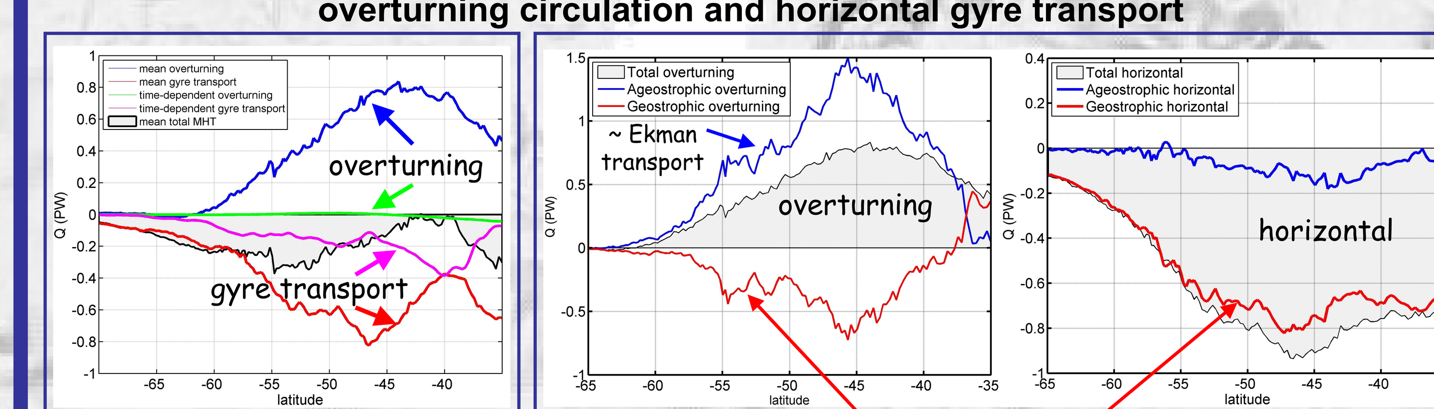
**Global Ocean:**
the portion of the interannual (**black curve**) and the total (**red curve**) MHT variance explained by the interannual EHT

## 5. Mechanisms of the MHT in the Southern Ocean

In the Southern Ocean (SO) the *overturning circulation* is maintained by the upper-layer northward Ekman transport induced by westerly winds, southward advection of the North Atlantic Deep Water in the intermediate layer, and the northward transport of the Antarctic Bottom Water formed around Antarctica. The *horizontal gyre transport* is provided by the Antarctic Circumpolar Current (ACC) and its branches.



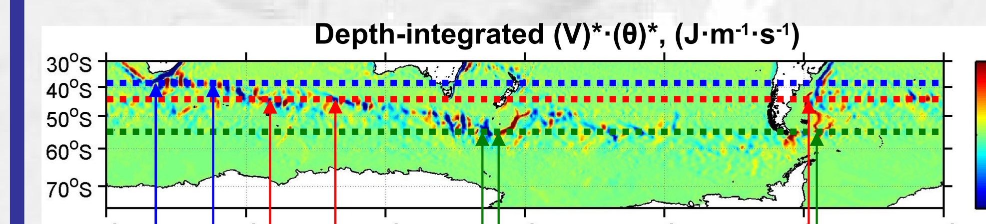

**MHT due to the time-mean/time-dependent and the geostrophic/ageostrophic overturning circulation and horizontal gyre transport**



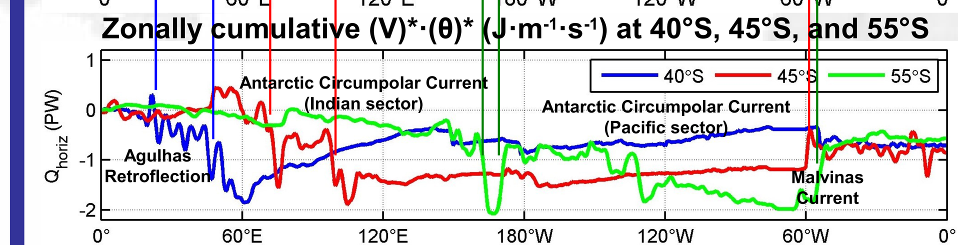

Poleward MHT due to the horizontal gyre transport (ACC and eddies) compensates for the strong equatorward MHT due to the overturning circulation and results in the southward total MHT in the SO.

MHT due to the **geostrophic circulation** balances MHT due to the **Ekman transport** and maintains the southward MHT in the SO. The MHT due to the geostrophic horizontal circulation is mainly caused by the warm ACC southeastward transport in the Indian sector of the SO and by the cold northward transport of the Malvinas Current in the Argentine Basin.

**Depth-integrated $(V)^*\cdot(\theta)^*$, ($J\cdot m^{-1}\cdot s^{-1}$)**



**Zonally cumulative $(V)^*\cdot(\theta)^*$ ($J\cdot m^{-1}\cdot s^{-1}$) at 40°S, 45°S, and 55°S**




**Relative importance of the Southern Ocean sectors:**

The Indian sector of the SO, where the ACC flows southeastward, is responsible for most of the southward MHT due to the horizontal gyre transport.